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Technical Memorandum

ENVIRONMENTAL REQUIREMENTS
FOR
SIMULATED HELICOPTER/VTOL OPERATIONS
FROM
SMALL SHIPS AND CARRIERS

Lieutenant C. W. Woomer, USN
Rotary Wing Aircraft Test Directorate
And
Mr. R. L. Williams
McDonnell Douglas Electronics Company

12 April 1978

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DEPARTMENT OF THE NAVY
NAVAL AIR TEST CENTER

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Helicopter/VTOL operations from ships create demanding flying qualities and performance requirements. The environment in which takeoff and landing evolutions must occur has a significant influence on these tasks. Aircraft and simulator designers, each in their own way, must make appropriate provision for environmental factors, such as visual landing aids (VLA), ship motion, turbulence, relative wind, and ground effect. over

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The unique characteristics of a helicopter combined with the shipboard operations of a naval environment have been successfully simulated in Device 2F106, the SH-2F Weapons System Trainer (WST). It is equipped with a VITAL III computer-generated image (CGI) calligraphic visual system. The development and validation of this device have provided valuable experience on environmental requirements needed to perform takeoff and landing tasks from ships. Technical advances in the state-of-the-art of CGI visual systems now offer capabilities which overcome many previous limitations. This permits additional tasks to be successfully simulated, improving the safety and economics of training.

The paper discusses the specific requirements for the simulated environment to satisfactorily provide training for shipboard takeoff and landing. Test techniques to validate trainer fidelity in flying qualities, performance, and environmental simulation are discussed. The specific subject of calligraphic visual systems is extensively covered, including a report on the current state-of-the-art as related to the at-sea environment. Finally, the utilization of a high-fidelity trainer is explored for research as well as for expanded fleet training.

PREFACE

This technical memorandum is based on experience gained by the authors while associated with the SH-2F WST, Device 2F106 program. Background in shipboard operations was gained from one author's fleet experience and participation in ongoing Dynamic Interface programs at NAVAIRTESTCEN. The paper was prepared for presentation at the Flight Mechanics Panel Specialists' Meeting on Piloted Aircraft Environmental Simulation Techniques, Advisory Group for Aerospace Research and Development (AGARD), NATO, to be held at Brussels, Belgium, from 24-27 April 1978. The objectives of this meeting are to review and exchange information on the general state-of-the-art and special-purpose mission applications of environmental simulation techniques. The contents of this memorandum have been reviewed by flight test and/or training device specialists at NAVAIRTESTCEN, Naval Training Equipment Center, and industry.

APPROVED FOR RELEASE

J. H. Foxgrover

J. H. FOXGROVER, RADM, USN
Commander, Naval Air Test Center

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SUMMARY

Helicopter/VTOL operations from ships create demanding flying qualities and performance requirements. The environment in which takeoff and landing evolutions must occur has a significant influence on these tasks. Aircraft and simulator designers, each in their own way, must make appropriate provision for environmental factors, such as visual landing aids (VLA), ship motion, turbulence, relative wind, and ground effect.

The unique characteristics of a helicopter combined with the shipboard operations of a naval environment have been successfully simulated in Device 2F106, the SH-2F Weapons System Trainer (WST). It is equipped with a VITAL III computer-generated image (CGI) calligraphic visual system. The development and validation of this device have provided valuable experience on environmental requirements needed to perform takeoff and landing tasks from ships. Technical advances in the state-of-the-art of CGI visual systems now offer capabilities which overcome many previous limitations. This permits additional tasks to be successfully simulated, improving the safety and economics of training.

The paper discusses the specific requirements for the simulated environment to satisfactorily provide training for shipboard takeoff and landing. Test techniques to validate trainer fidelity in flying qualities, performance, and environmental simulation are discussed. The specific subject of calligraphic visual systems is extensively covered, including a report on the current state-of-the-art as related to the at-sea environment. Finally, the utilization of a high-fidelity trainer is explored for research as well as for expanded fleet training.

BACKGROUND

SHIPBOARD TAKEOFF AND LANDING TASKS

The future of the United States Navy (USN) will be radically changed by several programs now in progress concerning the dispersal of aviation units on ships at sea. Presently, one or more of six different types of helicopters are operated to some extent from nearly every major USN ship. Fleet introduction of the SH-60B helicopter, commonly referred to as the Light Airborne Multipurpose System (LAMPS MK III), will greatly increase the number of small-deck operations routinely conducted. Research on and development of Vertical/Short Takeoff and Landing (V/STOL) aircraft are now receiving very high priority within the United States Naval Aviation community. The purpose of the V/STOL Type A effort is to determine whether different models of a minimum number of basic subsonic V/STOL aircraft could replace the various existing fixed and rotary wing aircraft. Dispersal of these aircraft on ships other than large aircraft carriers (CV) is a primary goal of the program.

Shipboard compatibility is an important part of the LAMPS MK III program and is generally considered the overriding design goal of any Navy V/STOL proposal. Static interface in the form of deck structure, rotor and airframe clearance, VLA, navigation aids, etc., is formally inspected and requires certification. This certification of a specific ship is categorized, depending on the facilities provided, into one each of three levels and seven classes for a specific helicopter type. The

Naval Air Engineering Center (NAVAIRENGCEN) performs this comprehensive evaluation. Highlights of the aviation facilities ship helicopter certification program are contained in reference 1.

Static interface provides only a portion of the overall ship/aircraft integration. After certification that a ship can accommodate and service an aircraft, a second phase of tests is required. Dynamic Interface (DI) is the determination of the specific launch/recovery capabilities of a particular helicopter and ship combination in the at-sea environment. DI is one type of flight testing carried on by the Naval Air Test Center (NAVAIRTESTCEN). This testing is intended to provide a safe operational flight envelope for fleet usage. The cumulative effect of factors such as ship motion, ship-generated turbulence, obstructions, VLA, field of view (FOV), and wind over deck establish the test environment. Aircraft flying qualities and performance are then evaluated in this environment to establish actual takeoff and landing limitations. Test results are published in reference 2 as Launch/Recovery envelopes in terms of ship motion and relative wind velocity.

Real emphasis in the area of helicopter/ship interface in the USN has developed only within the last 9 years and has roughly paralleled the development of the LAMPS MK I and MK III. The decks are small; clearances are often less than 5 feet. The lighting package of the ship provides the only approach and landing aids. There are no automatic approaches, cockpit instrument glide slope indicators, closure rate indicators, nor any heads-up displays. The approach commences in a landing configuration in cruise flight similar to a fixed wing aircraft. A descending, decelerating, constant glide slope angle type approach is employed. Prior to landing, a transition to hovering flight based on visual reference to a moving platform must be made. This platform on a conventional mono-hulled ship is generally in motion in all 6 degrees of freedom. Figure 1 illustrates the pilot's view of the landing area. Personnel acting as landing signal directors provide advisory information and with experience can predict ship lull periods which provide the best opportunity for landing. Depending on the size and flying qualities of a particular aircraft, it may be held in a hover either just short of the ship or actually over the flight deck. This position is maintained until the quiescent period approaches, at which time the landing is commenced. Vertical landing is required within the confines of a 24-foot circle painted on the deck. Once the decision to land has been made, the maneuver is made expeditiously. Exacting positional control must be maintained from initial positioning in the landing area until on deck. The complexity of the task of landing aboard a small ship is documented by the extent of the test and evaluation (T&E) efforts described above for establishment of operating limits.

Research and development of more modern aids to landing aboard small ships are currently being considered as part of the LAMPS MK III and, more especially, the V/STOL Type A programs. Haul-down systems are being considered with designs based on existing Allied operational systems. Improved visual glide slope indicators as well as cockpit-displayed glide slopes are being evaluated. Improved shipboard lighting packages and heads-up displays (including a closure rate presentation) are under consideration. It has even been proposed that a control command system be developed that would permit a completely automatic approach and landing.

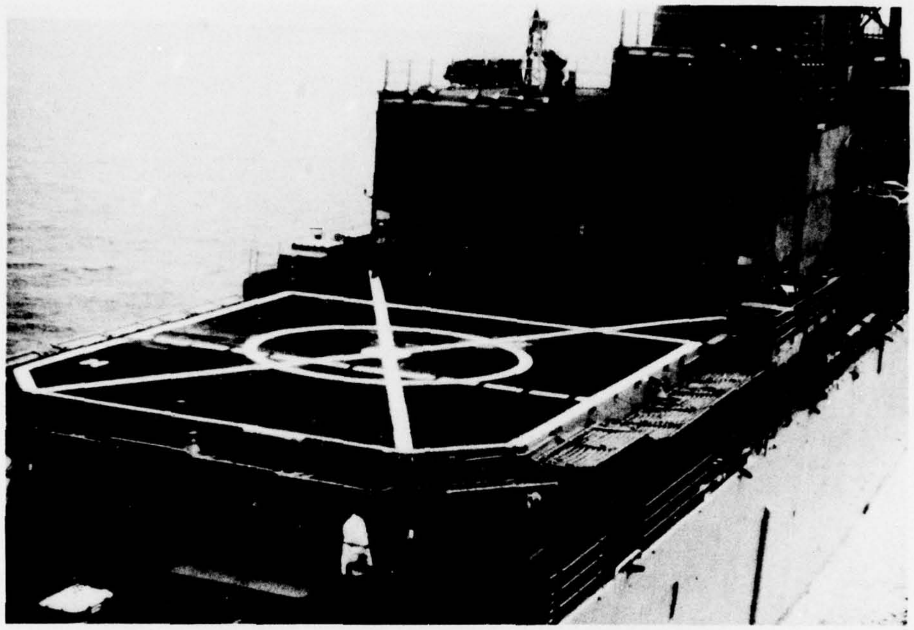

Figure 1
DD-963 from Approach

The SH-2F aircraft holds the designation as LAMPS MK I. It is presently being employed around the world on USN ships for the antisubmarine warfare mission. As such, it has been the subject of many DI evaluations. Recently, NAVAIRTESTCEN devoted considerable effort to the development and evaluation of a full WST for this aircraft.

SH-2F WST EXPERIENCE

The SH-2F WST Device 2F106, presented in figure 2, is the first modern USN helicopter simulator and is intended to provide LAMPS MK I crew training. It was developed for the USN by Reflectone, Incorporated, Stanford, Connecticut. Extensive effort was applied by both the contractor and the Navy on the subject of flying qualities and performance. Technical evaluations of both the aircraft and trainer were conducted by qualified flight test personnel including engineers and test pilots. Flight test instrumentation requirements in the trainer were similar to that of the aircraft. Data were directly compared and used as a basis for establishing flight fidelity.

Subsystems such as motion, sound, and visual add to the simulated environment. The visual system display configuration consists of three units oriented to the pilot with a single forward repeater display for the copilot. The presentation is night-only CGI. In addition to specific Naval Air Stations, scenes include both an aircraft carrier (CV) and a frigate (FF). These shipboard scenes were provided to increase training in tactical operations, including shipboard landing and takeoff. Ships and other tactical targets can be independently maneuvered via instructor control.

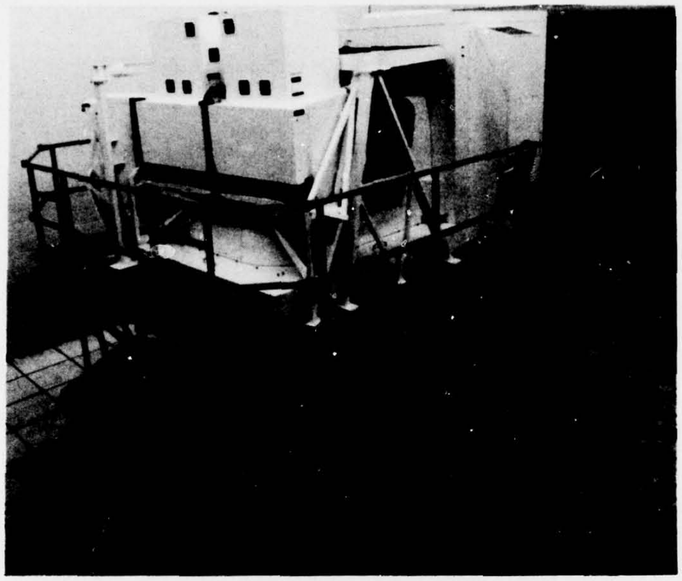

Figure 2
2F106 Visual Installation

The dynamic response of the visual system is of primary concern during target or ground-referenced maneuvers. In a helicopter trainer, the low altitude, low airspeed flight regime is particularly limited by the visual system lag times. These lag times represent the response delay measured between simulator and visual attitude. Simulator computation, data transfer, visual system computation, and display requirements each contribute to lag time. Pilot-induced oscillations and overcontrol are common problems when lag times are a significant part of the dynamic response. This is particularly true in closed-loop maneuvers, such as hover. Lag times in the SH-2F WST are approximately 300 milliseconds and result in reduced training effectiveness in these areas.

The FOV of Device 2F106 is presented in figures 3 and 4. Specific flight testing of this configuration was not accomplished. It was based on a consensus reached between instructor pilots and the contractor, given the apparently obvious factors governing visual system configuration. In particular, the physical mounting area required by the displays was a real limitation on this small cockpit.

Scene content was studied and developed in an attempt to construct a reasonable likeness of the aircraft carrier (CV) and frigate (FF). Effective aircraft carrier (CV) presentations had been previously developed for other USN trainers (F-14 and S-3A). The frigate (FF) model was a new development for this program. Significant features of the VLA were provided. The effect on pilot performance (beyond the most obvious requirements) was not necessarily considered in the scene construction. Occultation was not available in this system and, as a result, one surface could not obscure another (i.e., hangar face in front of horizon). Ship motion was programmed; however, no ship-generated turbulence was present. Ground effect was provided, as were engine and rotor sounds and landing gear reactions.

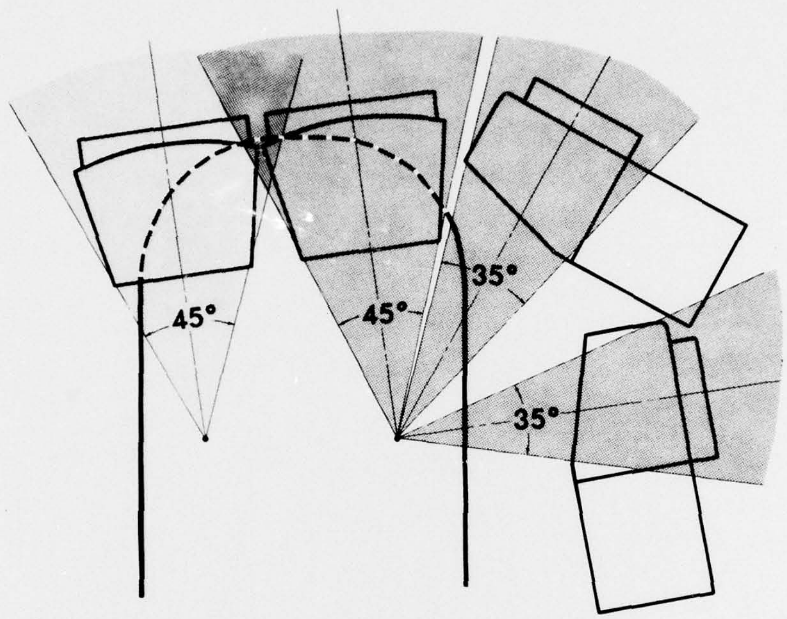

Figure 3
LAMPS SH-2F Display Unit Layout

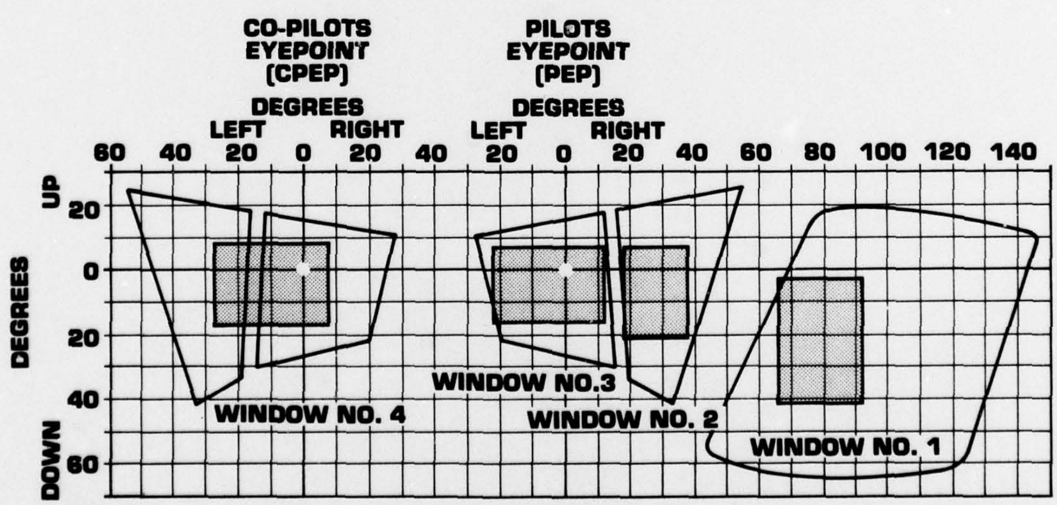

Figure 4
Helicopter Vision Plot/SH-2F
(Cylindrical Projection)

The results of the SH-2F WST development provided significant information on the environmental requirements for meaningful helicopter/shipboard simulation. Up and a''ay flight was enhanced by the visual system. Approach phases of shipboard operations were considered extremely useful for pilot training. Run-on landings to the field and carrier (CV), similar to those accomplished by fixed wing aircraft, were also satisfactory. These run-on landings generally require only forward FOV and are much less dynamic than transition to and landing from a hover. Normal instrument scan, a steady rate of descent and a good lineup accomplished during the approach phase resulted in satisfactory landings. Some overcorrection was required due to an incorrect ground effects model, but this caused only minimal problems. Hover landings ashore or aboard the aircraft carrier (CV) required significantly increased pilot workload. As altitude and airspeed were decreased, greater reliance on visual cues naturally occurred. Although control response fidelity in hover was specifically verified, pilot perception of dynamic response was directly affected by the visual system lag time. The limited FOV was found to be insufficient in look-down angles, both forward and laterally. Lack of lateral reference resulted in increased pilot workload and overcontrol during low speed flight and hover. However, large area targets, such as the flight deck of the aircraft carrier (CV), allowed visual reference to distant features. Excessively strong ground effect, a discrepancy in Device 2F106, added to pilot workload. Successful hover landings could be accomplished, although increased pilot workload and compensation were required.

During frigate (FF) approaches, visual reference was lost as the deck edge was crossed due to trainer FOV limitations. From hover height of 15 feet over the deck, no appreciable amount of the flight deck could be seen. Minimal assistance was provided by the hangar face, due to its lack of texture and detail, and the transparency of the superstructure resulting from the lack of occultation. Positional reference to the simulated ship was not reasonable once the deck edge was crossed. As a result, training in frigate (FF) landings was not recommended for the SH-2F WST. Shipboard landing is a major portion of LAMPS training and is a highly desirable capability for the simulator, yet it had to be removed from the planned training syllabus.

DEVELOPMENT OF CALLIGRAPHIC VISUAL SIMULATION

The use of computers to produce a visual scene for airline pilot training is now starting its seventh year. In that short time, CGI visuals for flight simulators have almost completely supplanted every other type of equipment being ordered by the airlines and by the military. In fact, they are now being purchased as outright replacements for some of the older television model board and film type systems. Relatively low acquisition and operating costs as well as flexibility for expanded training capability are the prime reasons for this acceptance.

The visual equipment responsible for this dramatic change comes from a technology usually identified as "calligraphic" - a convenient extension of the word more commonly associated with penmanship, either in its antiquated or its artistic meaning. In computer graphics, the word calligraphic applies to the equipment which makes line drawings on the face of a cathode ray tube (CRT) and the technique employed to convey digital information in picture-like format.

The pilot of a flight simulator equipped with a calligraphic visual system is the object of a delusion. It is deliberate because the value of the equipment resides in the illusion it creates. The real-world illusion achieved by a calligraphic visual system is, in fact, quite good, producing scenes outside the simulator windshields that are very realistic in appearance and geometrically accurate. Pilots accept the illusion enthusiastically.

When the first VITAL II visual simulation system went into service, a little over 6 years ago, it initiated changes into the then-existing philosophies of simulator training which are just now gaining momentum. Being the first CGI visual to be used for training, it eliminated many of the shortcomings of its predecessor systems. In spite of the night-only characteristic of this system, which displayed lightpoints only, the U.S. Federal Aviation Administration (FAA) officials authorized the use of VITAL II for commercial airline training. This approval included initial, upgrade, and transition training, as well as proficiency checks to the full extent permitted by the regulation (FAA Parts 62 and 121). The reason given was quite simple: VITAL II presented all of the visual cues desirable and necessary for such training, and these cues were presented more accurately and realistically than with the older types of systems.

Other manufacturers soon joined in. The result is that over 50 of the world's airlines and many military services (see Appendix A) have incorporated systems of this general type and are relying on them heavily for present and future pilot training needs.

The earlier calligraphic visuals, while very realistic, were composed completely of lightpoints on a black background and were primarily useful for approaches to landings rather than to landing itself. When greater attention was given to actual touchdown of the aircraft, a second generation of these visuals was developed. Thus, the systems incorporated textured surfaces to complement the lightpoints. With this surface technique, the runway surface itself with associated paint stripes and markings as well as airport structures was simulated as it would appear under aircraft landing light illumination. It was found that this surfacing capability could also be applied to ship simulation in depicting hull, deck, superstructure, and VLA. Figure 5 illustrates the evolution of the aircraft carrier (CV) scene with these developments. This is the technology chosen by the USN for the SH-2F WST, the first unit of which was placed in operation in July 1976 at NAS Norfolk, Virginia; a second system was accepted at NAS North Island, California, in November 1976. This system, called VITAL III, is the first helicopter application of CGI visual technology. Further developments in calligraphic visual simulation will be discussed in the latter part of this paper.

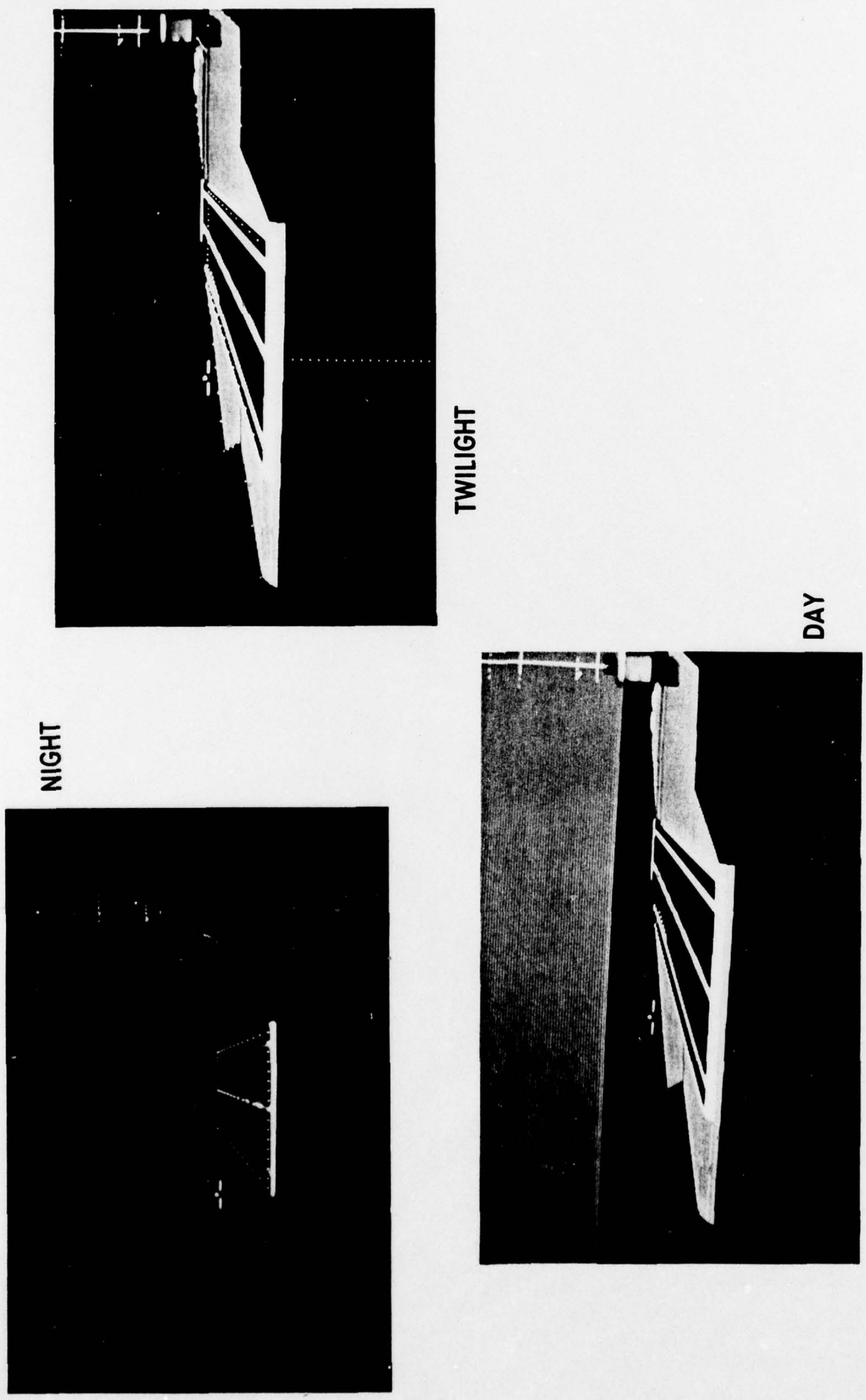

Figure 5
Three Generations of Aircraft Carrier (CV) Scene

REQUIREMENTS

DYNAMIC RESPONSE FIDELITY

Modern trainers are used for extensive tactical maneuvering and high workload closed-loop tasks. If positive training is to result, high fidelity with the actual aircraft is necessary. Reinforcement of learned techniques should be available between the trainer and the aircraft. This is particularly important in high workload tasks where, once learned, responses become nearly automatic. Aircraft limitations based on both flying qualities and performance characteristics are essential pilot cues during maneuvers such as shipboard landings. As such, they are part of the environment confronting the pilot.

VISUAL SYSTEM

The dynamic response of the visual system in an overwhelming factor in its suitability for pilot training. Lags in response, as mentioned earlier, are only tolerable to a maximum of a few hundred milliseconds. Mission relation may dictate sharply reduced maximum tolerable lag times. Prediction routines for attitude changes may be necessary to reduce lag times and have been used successfully. On the other hand, jerky and unstable motion of the scene often result from prediction routines that are forced to excess. This condition may be even more unsatisfactory than the lag time and can be disorienting and even nauseating to the pilot. Visual system dynamic response must also remain in phase and produce full amplitude displacements. Response in all axes must be capable of matching the vehicle being simulated. For example, yaw response in helicopter is much more demanding than that of fixed wing aircraft. Dynamic response is a limiting factor in the suitability of visual system integration for pilot training. However, it is also important to recognize that the visual system will dramatically illustrate basic simulator program weaknesses. Visual systems can be made to accurately track the host program and still not be suitable for training. In this case, modifications to the basic trainer program are required.

The FOV of a visual system is critical to the accomplishment of simulator training tasks. The importance of mission relation to the design cannot be overemphasized. In particular, acceptable fixed wing visual configurations should not necessarily be considered satisfactory for helicopter/VSTOL applications. In general, these trainers should be provided with maximum coverage. For landings on small-deck ships, this is particularly true since the entire deck could be out of view from normal over heights. Selectable, moving, and wide-angle display configurations should each be considered, based on mission requirements. Ultimately, an identical FOV to that of the aircraft is desirable. Until such time as the state-of-the-art can economically provide this capability, a training limitation is being created and optimization of the available FOV is critical.

The term "scene content" encompasses many specific items. A reasonable facsimile of the specific ship is a basic requirement. Detailed representation of the hull, superstructure, and primary obstructions must be provided in proper perspective. The simulation must be an independently moving model within the visual scene. It must be free to move with instructor-commanded changes in course, speed, and sea state. Landing area markings must be provided in exact detail. Floodlighting must be provided in terms of relative intensity and be

controllable by the instructor acting as the Helicopter Control Officer (HCO). The entire package of VLA must be presented exactly as installed, including directionality, intensity, position, flashing, strobing, and color. A summary of the existing VLA used by the USN is presented in figure 6. Control of the individual elements of this package needs to be provided for training in degraded mode operation. Relative sizes and locations are critical, since at present the only closure rate cue is the relative "spread" of specific elements of the VLA as the helicopter approaches the ship. Relative sizes are also important to establish proper perspective of the scene. Figure 7 illustrates the frigate (FF) presently used in the SH-2F WST. Surface discontinuity and texturing should be employed to provide improved perspective. Homogenous surfaces, presented close-in and used as primary references, tend to cause a loss of perspective. This is particularly true of "pure" runways and hangar faces when attempting to hover, land, or takeoff. A display nearly filled by a purely homogenous surface provides no cue to movement until the FOV extends beyond that surface. More intensity in scene content concentrated in areas of intended landing is a specific requirement of VTOL operations. Imaginative presentations could result in significant improvement in pilot performance. Additional visual scene requirements should include tactical elements such as independently moving targets consisting of freighters, trawlers, submarines, smoke markers, and sonobuoys.

Occultation, or the masking of scene content by an intervening surface, could add significantly to the depth and perspective of a scene. In land-based scenes, hangars blocking background cityscapes would add to the sense of motion presently lacking at low altitude and low speed. Aboard ships the requirement for occultation is mandatory. Horizons passing through ships' superstructures are intolerable. The horizon image appears to take precedence over other scene content and relative position to the ship is lost. On systems where occultation is not available, such as that on the 2F106, the impact was considered so great that alternate measures were devised. For work aboard the frigate (FF), a routine was devised in which the hangar face coverage of a specific display unit was monitored. When a specified percentage of the display was filled by hangar surface, the horizon was automatically switched off (in that display only). This artificiality was considered much less distracting than the horizon show-through discussed earlier.

Details of scene content often used in actual flight must be considered objectively in visual design. Ocean surface and ship wakes may be detracting, as presented, and better not included. This is particularly true if no dynamic presentation is proposed. All CGI visual systems, regardless of make, have a limited capability for displaying surfaces and lightpoints. Consideration must be given to actual mission requirements so that this limited amount of scene content is not wasted on so-called "eye wash" or elements that may be nice to have but that do not contribute to training.

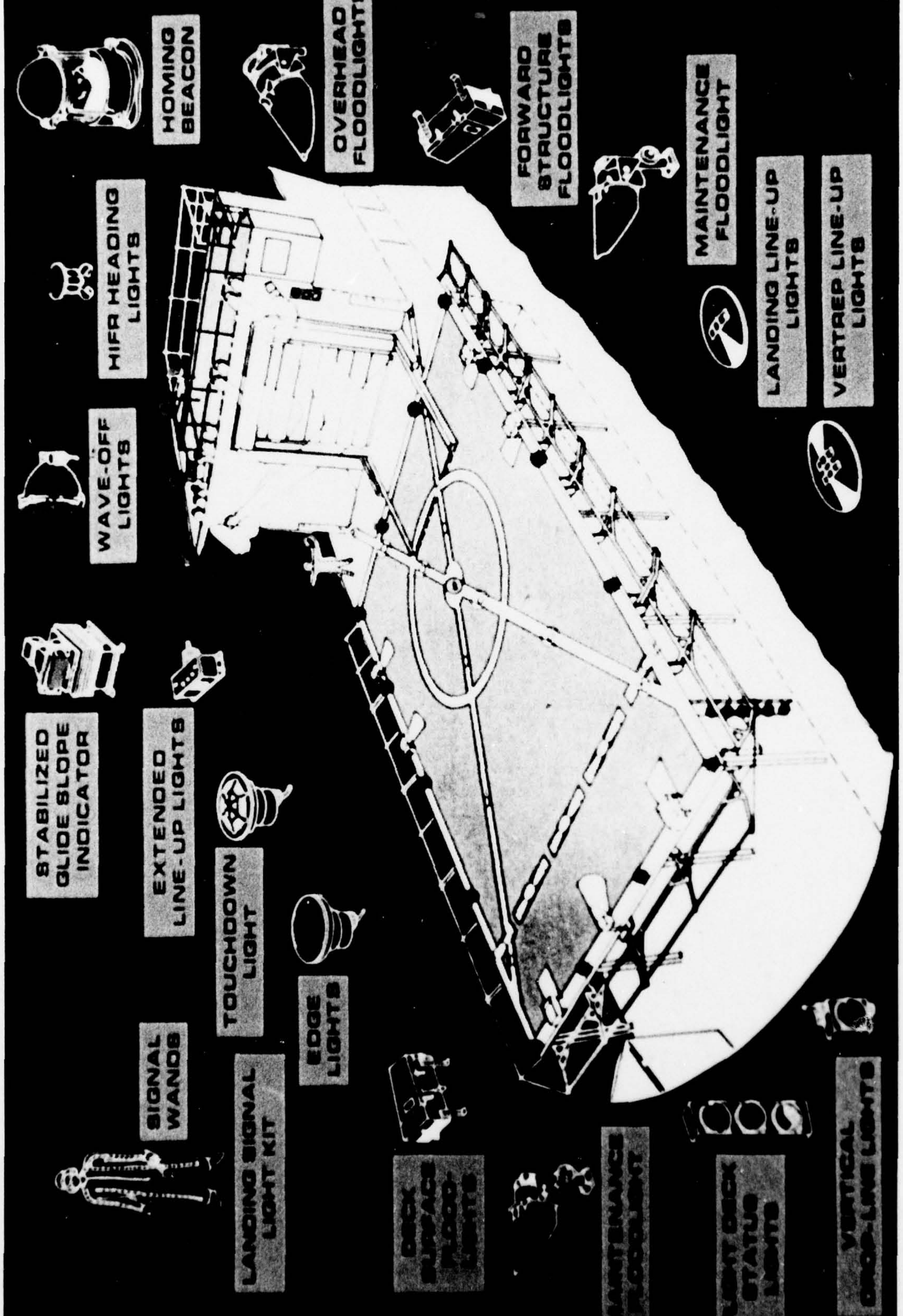

Figure 6
VLA Requirements

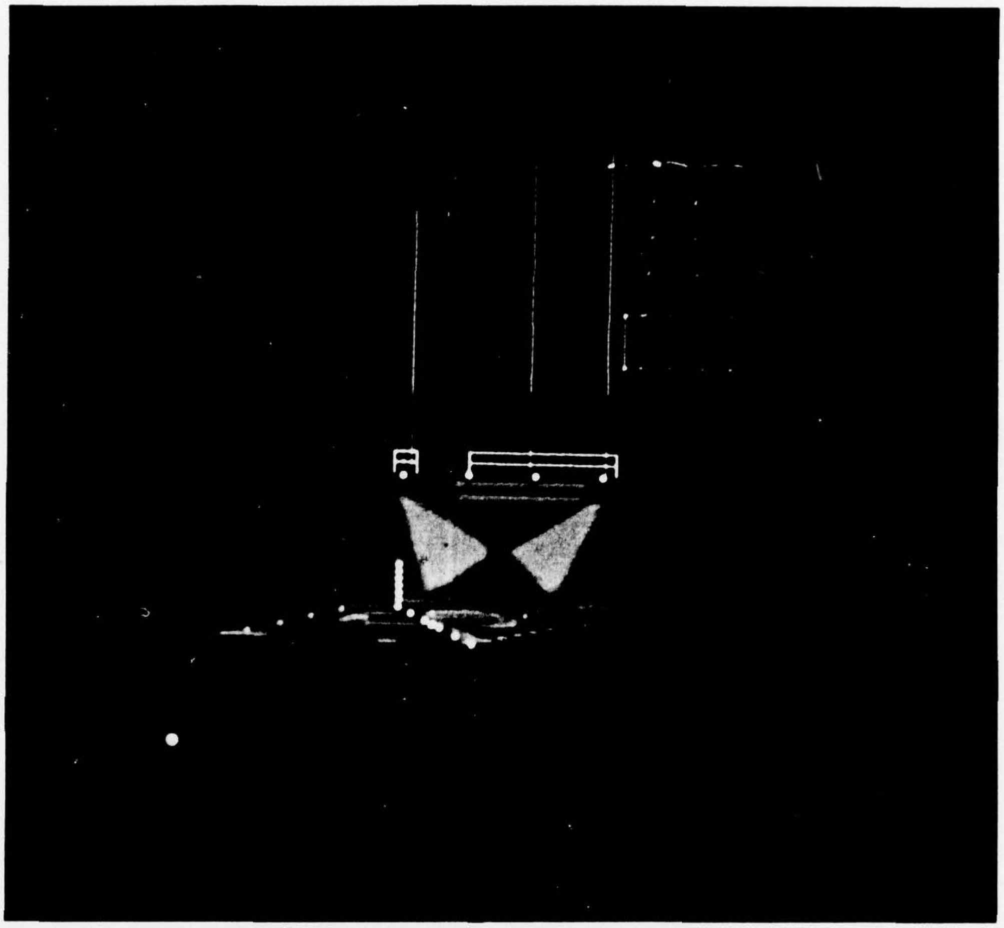

Figure 7
Frigate (FF) Night Scene

MOTION SYSTEM

A full 6 degrees of freedom motion system appears to be not only appropriate but a necessity to VTOL trainers. Figure 8 illustrates the type motion base used by the SH-2F WST. Significantly improved pilot performance has been noted with the inclusion of the system. Added cues provided by the motion system seem most helpful in flight at low speed and/or during degraded modes of the automatic flight control system. Emphasis should be placed by the contractor on matching the motion and visual systems response. This is necessary to prevent confusion of the pilot's sensory perception. Particular confusion is apparent when experiencing simulated shipboard motion without the motion system activated and the only cue is that provided by the visual system.

Ship motion models are necessary elements of the at-sea environment. Ship motion is a function of wind, sea state and direction, and relative heading of the ship. During approaches, the effects of ship motion on the VLA presentations are essential for positive training. Expanded experience with the dynamic "sight picture" of the VLA under various conditions is extremely valuable to fleet readiness and could have a direct impact on safety. Final phases of the approach

followed by hover and landing are based directly on a visual presentation of ship motion. With the aircraft on deck, ship motion simulation (using visual and motion systems) provides realistic exposure to the environment and allows the introduction to techniques of judging the period and lull of the ship. Proper simulation of landing gear reactions not only are necessary for landings but also for ship motion inputs while on deck. Coordination of the visual presentation is essential to the effective use of a ship motion model. Caution must be exercised not to exceed pilot limitations by attempting approaches and landings in the trainer well beyond those considered safe in actual operations. The modelled enviornment alone creates increased pilot workload. Lesser sea states than operational limits would be expected to require sufficient pilot workload for training purposes.

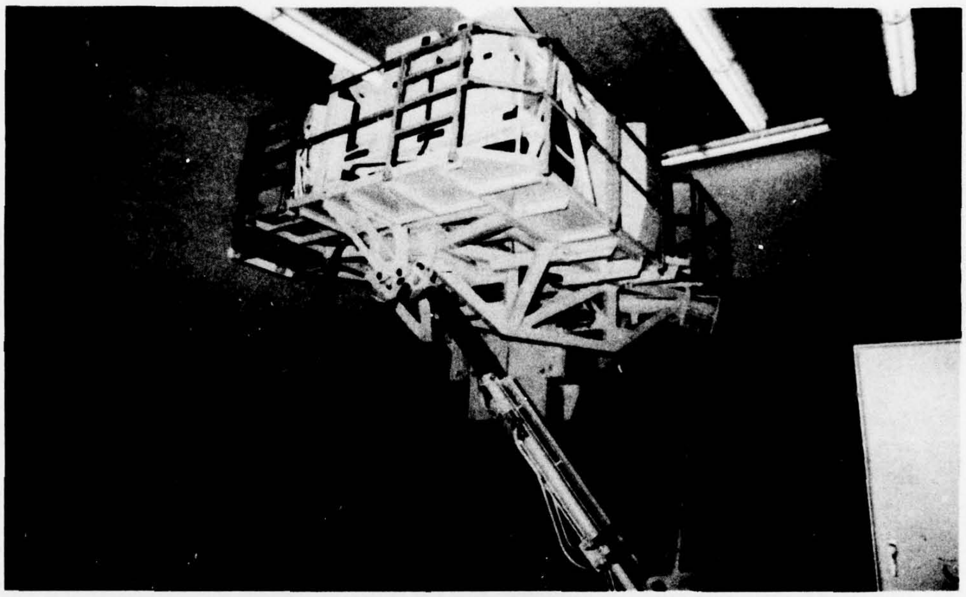

Figure 8
2F106 Motion Base

TURBULENCE

Turbulence models provide a disturbance in the "perfect atmosphere" of simulation. Motion-based trainers have a tremendous capability to introduce disturbances such as atmospheric turbulence and aircraft vibrations. Turbulence should be introduced through the motion system as well as the aerodynamic program to ensure that flight characteristics are not transparent to turbulence. Pilot workload should be increased as a function of turbulence. Visual systems must be capable of withstanding both the actual motion of the platform as well as the accelerations in the aerodynamic program without degradation in tracking performance during aircraft displacement. Another area to be considered is the subject of ship-generated turbulence. This environmental element is one of the primary limiting factors for operational envelopes and is evaluated in DI testing. A turbulence model for a frigate (FF) class ship has been developed. To be complete, it should include sources such as turbine exhausts, sinks such as large air intakes, downflow (commonly referred to as a "sinkhole") in the landing area immediately aft of a large hangar, downwind extension, and variation due to both wind and the dynamics of ship motion. Evaluation of this model is expected to be accomplished on the SH-2F WST following scheduled improvements to the visual system.

RELATIVE WIND

The computation and results of relative wind should be included in any shipboard simulation effort. Opertional envelopes produced from DI testing are presented in terms of relative wind. A detailed description of this phenomena is available in reference 3. Ship maneuvering with respect to the true wind must produce a shift in relative wind. This shift should be observed in the cockpit according to the peculiarities of the specific pitot-static system. If accurately modelled, the flying qualities and performance involved with takeoff and landing should vary with respect to the relative wind vector. Also, aircraft attitude required to track the approach path should vary as a function of the wind vector. Again, trainer launch/recovery conditions should not necessarily be selected at the extremes of the real envelope since equivalent workload will undoubtedly be achieved at lesser values.

GROUND EFFECT

Ground effects on flying qualities and performance are very significant in helicopter and V/STOL aircraft. The interrelationship of flying qualities and performance is inseparable in the low altitude, low speed flight regime. Fidelity in the ground effect model is essential if takeoffs and landings are to be accomplished in the trainer. In helicopters, natural reduction in rate of descent is provided by ground effect. For instance, if the ground effect is significantly stronger than it should be, ballooning may occur when close to the surface. Pilot reaction would be overcontrol with collective. A secondary result of this excessive vertical motion and collective movement could be coupled reactions in other axes. During shipboard operations, ground effect may be entered abruptly as the aircraft crosses the deck edge. In other types of VTOL aircraft, various ground effect phenomena may occur, including an increased rate of descent. Whatever the effect, the specific characteristics of this phenomena are essential elements of the environment.

SOUND SYSTEM

Sounds in present helicopters are primary cues of the status of engines and dynamic components. Commanded and uncommanded variations of the power train are normally detected initially by sound cues. For that reason, sound simulation is a basic element of the simulated environment. Pilot performance has been observed to improve with the addition of sounds driven by engines and rotor. Other sound elements which contribute to the environment are realistic sidetones for Intercommunication System and radios, background transmissions on recognized frequencies, such as approach control, and standardized controller transmissions.

TEST TECHNIQUES

FLYING QUALITIES AND PERFORMANCE

Aircraft flight test data must be used for references to establish the fidelity of a trainer. This type of data has become known as criteria data, which is in addition to the design data required by the contractor at the earliest stages of system layout. In a manner very similar to actual aircraft testing, the trainer should be evaluated by qualified flight test personnel. Additional aircraft testing

may be required specifically for the development of criteria data. Standard flight tests and techniques apply in most cases. Some unique test methods may need to be developed to compensate for the lack of a visual reference as an example. This effort should precede any attempt at visual system integration. A result of validation of basic program fidelity is the simplification of the task of visual system integration. Later, after visual system validation, specific improvements to the basic program can be accomplished using the visual system as an evaluation tool. A typical data comparison is presented in figure 9. A paper on the subject of technical evaluation of helicopter trainers was published as reference 4.

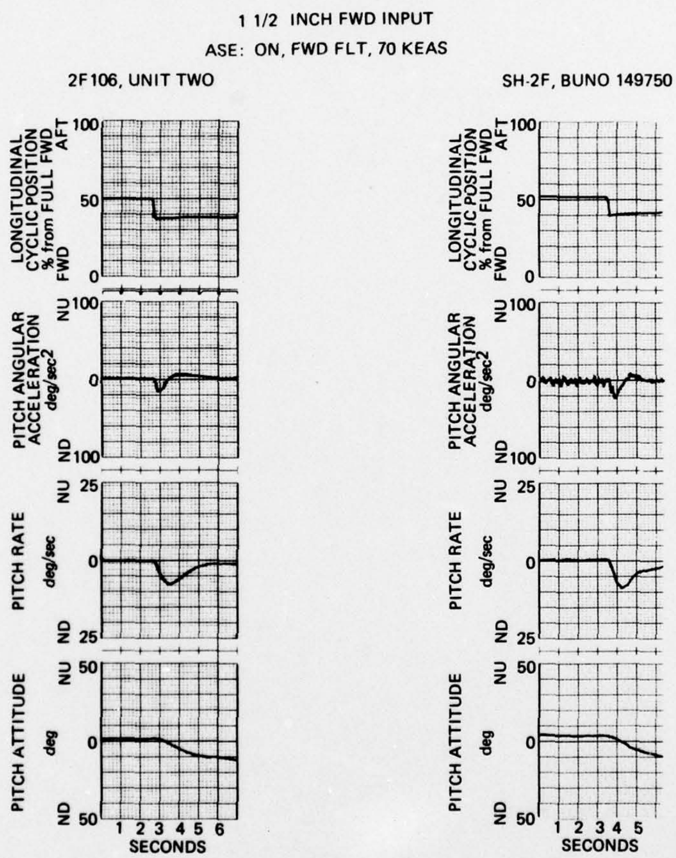

Figure 9
2F106 Flying Qualities Data Comparison

MOTION SYSTEM

Motion systems are tested by the contractor with proof loads and accelerometers during assembly. This is a substantiation of the algorithms inherent to the design and the physical response capabilities of the hydraulic actuator system. Research is presently being conducted at Naval Training Equipment Center on the optimization of these algorithms which vary with each contractor. It is possible that several optimum programs are required, depending on the type of aircraft: conventional fixed wing, single main rotor helicopter, tandem rotor helicopter, V/STOL, etc. Further T&E should be conducted on the motion system. Specifically, the motion response should be compared with both control inputs from the cockpit

and simulator aerodynamic response. Linear accelerations at this pilot's station as well as angular accelerations are required data for both aircraft and trainer. Particular attention should be paid to lag times and any differences between simulator program dynamics and motion response.

A third discussion while on the subject of motion systems should be that of vibrations. Models of both free air and ship-created turbulence should be based on specific research in those areas. Testing, in addition to the qualitative evaluations, should include analysis of attitudes, rates, and accelerations in each axis while being subjected to these disturbances. Vibrations inherent to the airframe are generally documented and available. Vibration test data should be used as specific criteria data for evaluation and tuning of the trainer. This type of tuning may need to be withheld until the trainer is actually in place and hard-mounted at its permanent facility.

SOUND SYSTEM

The sound system of a trainer is generally qualitatively evaluated. Data from the actual aircraft are provided in the form of recordings. These recordings are analyzed by the contractor to determine the specific character of individual sounds to be generated. Dynamic sounds are cued by other program modules such as the engine and rotor. Radio sidetones are established in the same manner.

VISUAL SYSTEM

The first step in the area of FOV is to determine the exact aircraft FOV available. A unique device, the Field of View Evaluation Apparatus (FOVEA), has been developed by NAVAIRTESTCEN for this purpose. Figure 10 is a picture of this equipment in use. Next, a discussion among the concerned parties, including engineers and pilots, is held to establish several options for display configurations to meet the training requirements. Plots from the FOVEA evaluation, figure 11, are used at this meeting as the background on which proportionally correct display overlays are arranged. The next phase requires the use of an aircraft. Ground tests are conducted by reproducing the proposed display configuration in the cockpit. Amber cellophane is cut to match the configuration and placed on the windows. Blue lens goggles are used by the pilot to cause a restricted FOV identical to that which would be available in the trainer. This setup is established for each potential configuration and evaluated. The purpose of this phase is to reduce the number of potential configurations to be flight tested. Finally, actual flight testing of each remaining configuration is accomplished. Specific mission-related tasks such as approach and landing on a mocked-up flight deck are performed. The result of this T&E effort is a specific design location for each display. In this manner, the capabilities and limitations of the visual system FOV to be installed are well understood. A detailed description of this FOV evaluation is available in reference 5.

Once the visual system is in place, the FOVEA can be used to document the actual installed locations. Alignment of the presentation across the several displays must be verified. Again, the FOVEA could be employed. A single straight edge such as the horizon or runway marker should be positioned in the FOV for a reference.

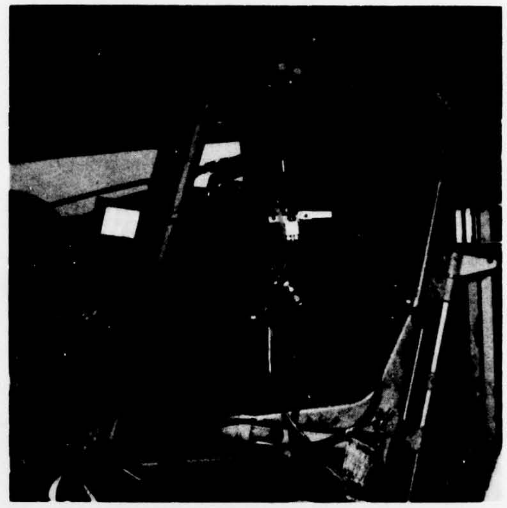

Figure 10
FOVEA Equipment

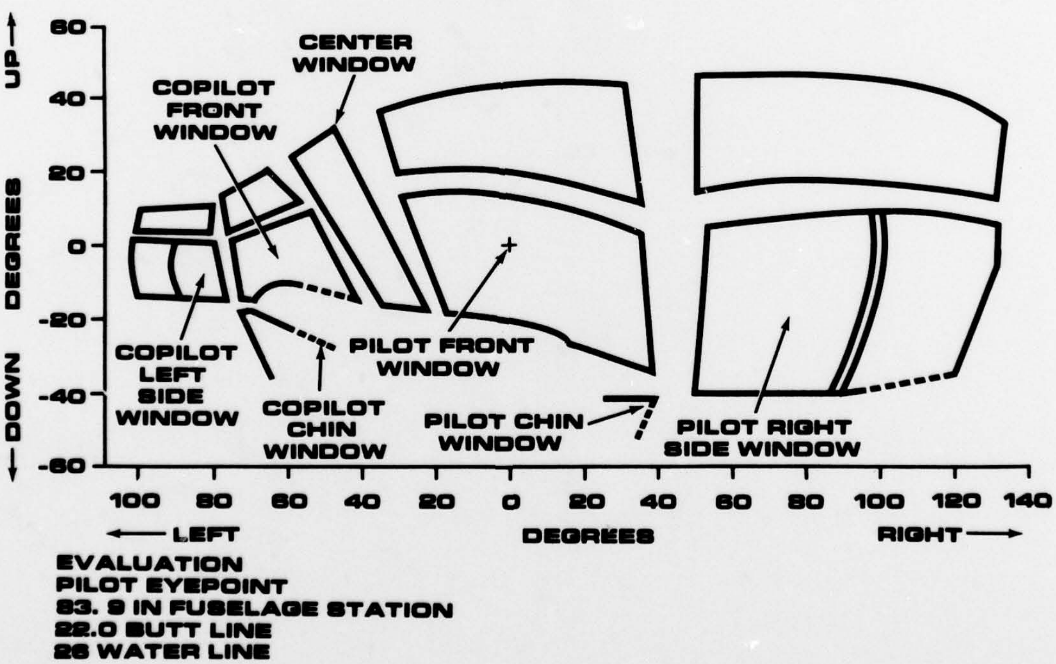

Figure 11
FOVEA Data Plot
CH-46E

Registration or synchronization of adjacent displays is qualitatively evaluated. Flight through various scenes while performing normal aircraft maneuvers quickly uncovers any problems with registration. The observance of apparent uneven shifting or tracking of adjacent displays is an indication of this problem. A subject for qualitative evaluation is shading of the displays. This is particularly a problem when units are mounted at various relative elevations or rotated 90 degrees from one another. Fixed gradients or computational schemes may have to be altered to present an even presentation across the several displays in the cockpit. This problem is very noticeable when in close proximity to a single homogenous surface such as the hangar face.

The basic qualitative evaluation performed in the past has been extensive flight throughout each scene. The purpose of this type of test is the identification of problems such as misplaced landmarks or the offset of major scene elements such as runways from simulated navigational aids. Various mission-related tasks should be performed to evaluate the effect of FOV and other visual system elements on pilot performance. The effect of scene content can be evaluated during development by interchanging visual programs of various scene intensity and repeating an individual maneuver. The element to be monitored is pilot workload required to accomplish the task. It may be desirable to perform this sort of an evaluation to determine tradeoff considerations, if required, between high scene density in landing areas and the continuation of scene over a larger area.

Quantitative testing of the visual system dynamic response should be accomplished early in the evaluation. Display unit data output is required for this test and must be provided by the contractor for use on-site. It is essential that these data correspond as closely as physically possible to the amplitude and timing of the scene as observed from the cockpit as illustrated in figure 12. Data in the form of time histories of control input, simulator attitude, and visual system attitude should be presented and compared. An example of this data is presented in figure 13. Lag times and amplitudes should be closely evaluated. Predictor routines can be evaluated with this test setup. Response due to control step inputs, reversals, pulses, and mission-related tasks should be analyzed. The procedure should be repeated in each axis. A detailed description of this procedure and its results are presented in reference 6.

A geometric perspective test is performed to ensure proper computed perspective of the scene. Calculation should be made to determine where the simulated aircraft should be positioned so that a known scene feature (edge of landing line, etc.) is exactly even with the edge of a display. This evaluation should be repeated for each display while only aircraft position is altered. The performance of this quick check ensures the proper computation of the scene's geometric perspective in each of the variously positioned display units.

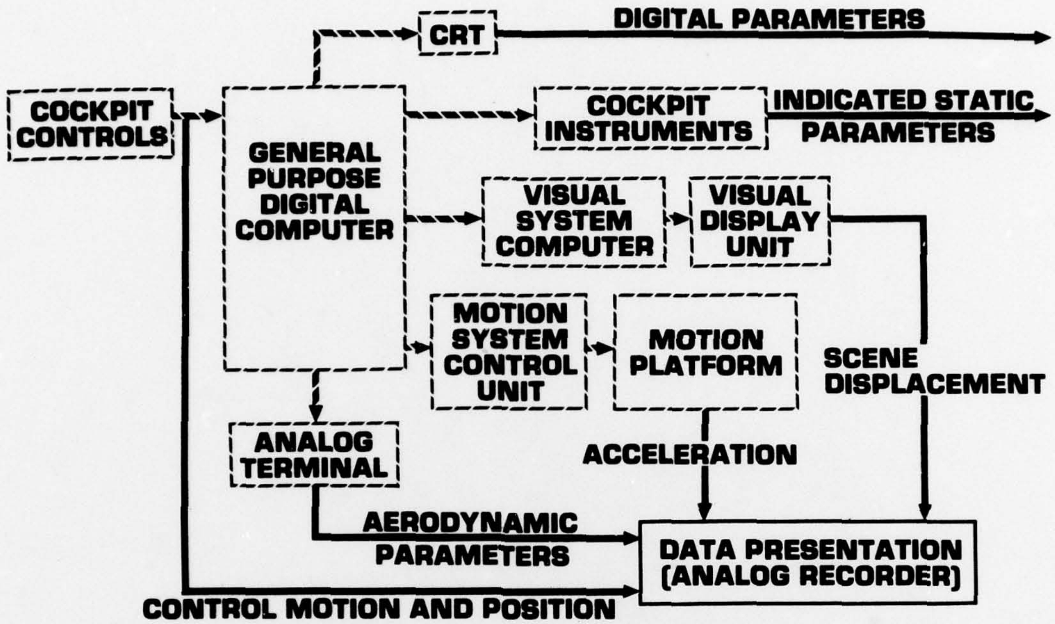

Figure 12
Block Diagram of Test Setup

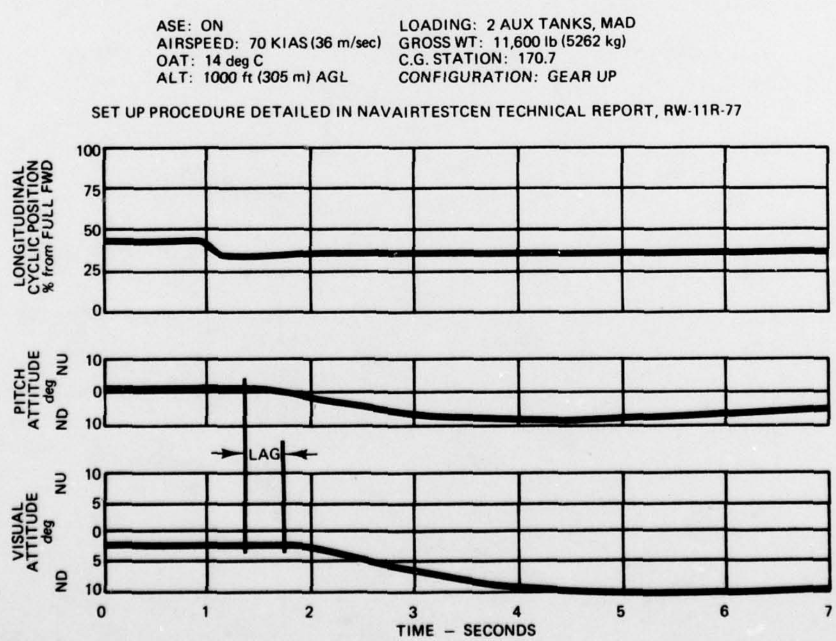

Figure 13
2F106 Visual System Data

STATE OF THE ART IN CALLIGRAPHIC VISUAL SYSTEMS

The next logical generation of this visual technology is now available. The calligraphic technology extends beyond what most observers had at first thought possible. With it, night scenes of greater complexity than previously produced plus twilight and day scenes are displayed. However, display brightness is limited by the beam penetration tubes utilized, to levels significantly lower than normal day simulation.

Efficient generation of surfaces has been the subject of considerable research. The surfacing device or picture controller is pipelined between a computer and a high-speed, color-graphics display unit. The device is designed to generate precision surfaces and lightpoints with minimal computer intervention. The latest generation of calligraphic CGI systems display multicolored day and twilight scenes while retaining the high-resolution characteristics of the earlier night scenes. What results is an imaging device which combines high resolution (unique to the calligraphic system) and high detail.

This new generation of calligraphic visuals promises to offer many additional training possibilities. Its predecessor with display of 2,000 lightpoints and 40 multicolored surfaces is superseded by the increased capability of over 8,000 lightpoints or over 300 multicolored surfaces. Special circuitry has been added to incorporate occultation so that three-dimensional objects appear solid (e.g., nontransparent ships, buildings, and mountains). Occultation is a new capability in the calligraphic system. Because it is new, its ultimate effect on scene quality is not yet fully understood. It will likely receive considerable attention and be part of the basis for future training applications.

This significant increase in quantities of surfaces and lightpoints will directly benefit programs involving the simulation of the ship/sea environment. It is anticipated, in fact, that an increased capability to 6,000 lightpoints (VITAL III 6000) will be incorporated into the SH-2F visual system. While only a portion of the frigate (FF) is presently modelled, the whole ship - in much greater detail - may be depicted. More complex detailing of the deck and hangar door will assist the pilot in positioning the aircraft on the landing area. Existing tactical targets presently portrayed by lightpoints may be simulated to the extent that the vessels may be identified as to class or type and by structure identification. The addition of a sea surface and pseudo wake effects offer potential for training in twilight environments. Recent developments can be applied to simulation of more subtle aspects of the environment. Visible fog can be portrayed during restricted visibility conditions. Realism can be added by simulating the reflections of landing lights, anticollision beacons, and aircraft sequencer strobes while transitioning through fog or cloud layers. Visible cloud bottoms and cloud tops can be portrayed while flying below or above the clouds. An example of the latest carrier (CV) scene is presented in figure 14.

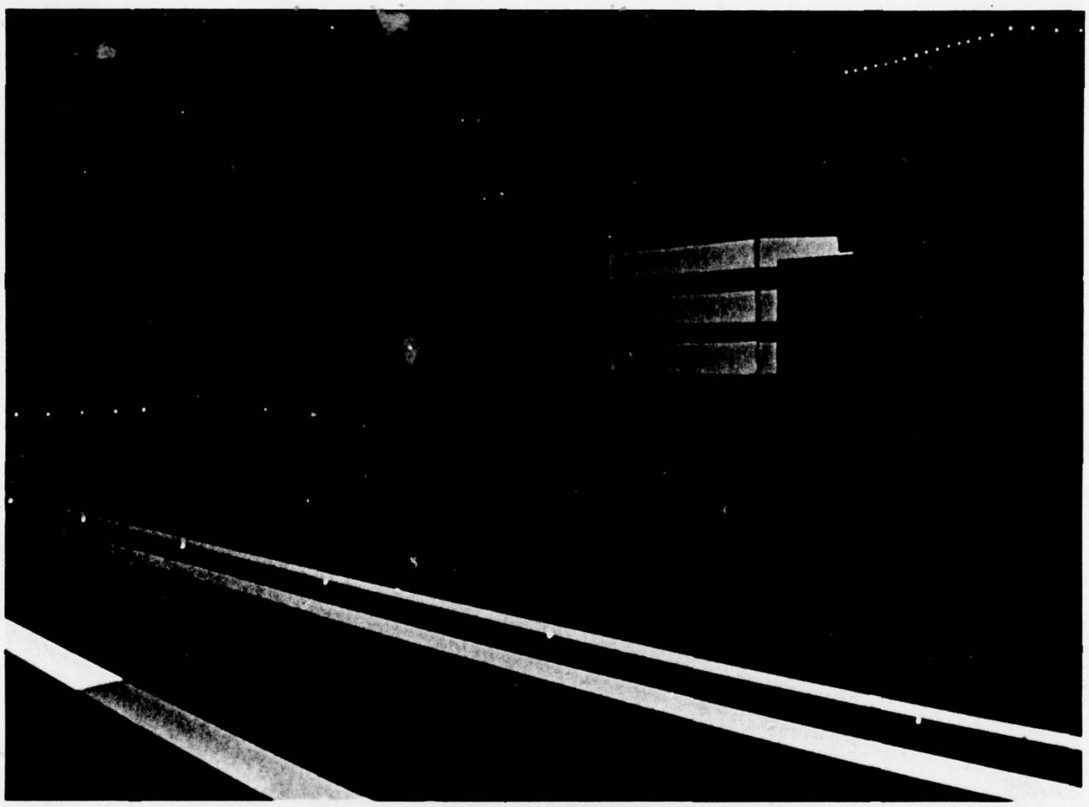

Figure 14
Carrier (CV) Scene

Another of the more important characteristics of newer calligraphic visual system is the capability to dynamically de-focus and focus scene elements under software program control. In unrestricted visibility conditions, this allows perspective growth of lightpoints as they approach the pilot's eye. Along with the accompanying intensity variance, this feature serves to reinforce the pilot's ability to judge distance to scene objects. This de-focus capability also serves to enhance the illusion when visibility is restricted. Runway lights or deck lights obscured properly appear de-focused with a halo effect as they disappear into the fog.

Another result of the improved technology has been a significant reduction in the visual system lagging the host simulator. As discussed previously in this paper, visual lags induce heavy workloads and control problems for the pilot. From the receipt of aircraft positional inputs from the host simulator computer, computation and display of new images are completed in less than 50 milliseconds. It has been found that simulated aircraft with high dynamics such as helicopters and fighter aircraft demand small visual lags in order to fly properly. The first application of the VITAL III update using VITAL IV image generation technology (designated VITAL III 6000) has been proven after incorporation into the U.S. Marines F-4J WST in Yuma, Arizona. The total transport lag, as represented in figure 15, has been demonstrated to be less than 50 milliseconds. Prediction compensation has not been required or utilized.

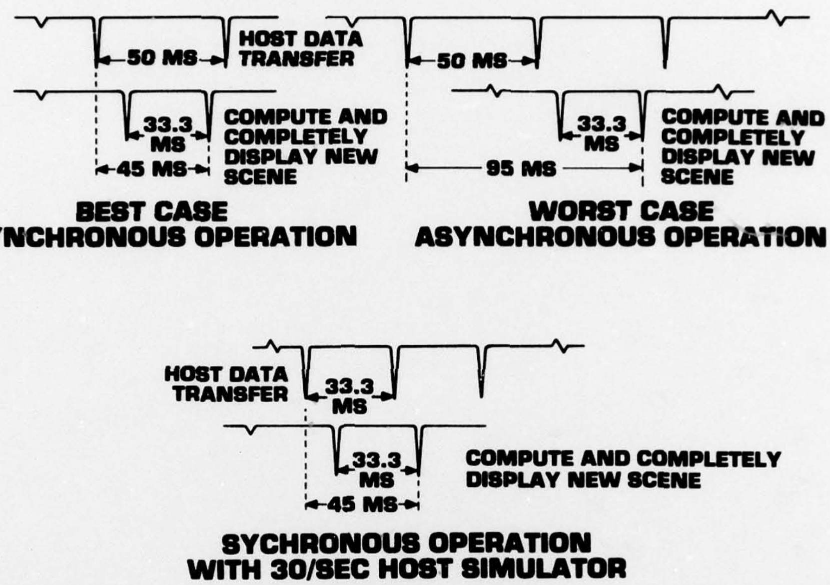

Figure 15
Simulator/Visual Data Transfer

In the past, gaming areas or environmental data bases have been restricted to finite areas. Airport scenes consisted of one data base, and other airports or ships were located on separate data bases. Flying from one airport to a ship, for instance, consisted of a takeoff and flying away from the modelled area and selecting the new data base, whereupon the display went blank for a period of time while the new data were loaded. New data base manipulation now permits display of contiguous areas of modelled scenes to automatically be loaded in real time from magnetic disc storage. It is now possible to fly uninterruptedly from shore to ship and return to alternate bases if desired.

Easier semi-automated methods of environment data base construction have been developed to complement the increase in surface and lightpoint capability. Reduction of map data to computer data base format can be accomplished by direct map digitizing. The map is affixed to a map digitizer tablet and with the use of a cursor device, the coordinates of map objects are directly transferred to the computer and compiled. Manual reduction of coordinates or extensive use of a keyboard/printer to construct an environment data base is no longer required. Alternative methods have also been developed where an environment can be modified from a CRT in a background mode while normal training continues in a fully interactive conversational mode. These devices should encourage user personnel to exercise the capabilities of the system to a greater extent.

FOV extension is the subject of much development work in visual systems today. The standard VITAL visual display, figure 16, used in the SH-2F LAMPS system has a total FOV of 45 degrees horizontal by 35 degrees vertical. Other display configurations are available to extend the FOV. Modules are available which edge register with only a 1 degree gap. Another configuration consists of two CRT electronics assemblies viewed through one optics unit, figure 17, resulting in an

uninterrupted 89 degree by 35 degree FOV. Yet, another display developed for the Royal Swedish Air Force JA-37 consists of three displays arranged in a narrow gap configuration around the pilot with three continuous channels of imagery. Each display channel is 45 degrees horizontal by 60 degrees vertical.

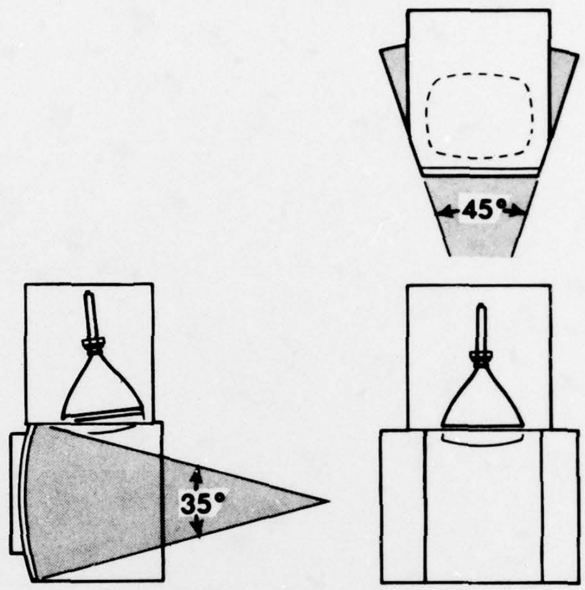

Figure 16
Basic Display Unit

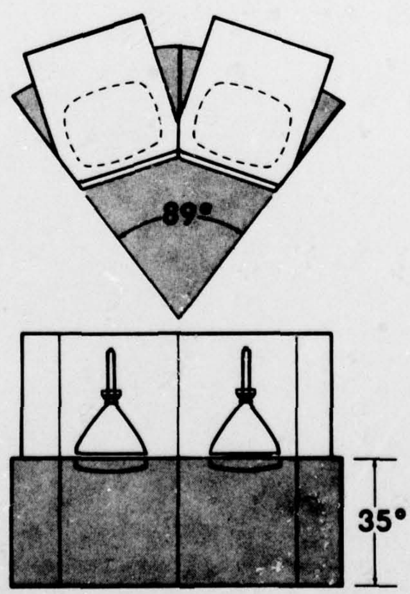

Figure 17
Optional Display Configuration

UTILIZATION OF HIGH FIDELITY TRAINER

TAKEOFF AND LANDING TRAINING

The most often repeated justification for flight simulators is reduced cost of operation. Costs of aircraft and fuel have escalated to the point that actual flight time is being reduced even with the realization of reduced readiness. For simulators to provide this replacement training, high fidelity trainers are required. As part of predeployment training, the simulator should be used heavily for tactical training. A second area for concentrated training and exposure is that of shipboard approaches, landings, and takeoffs. Practical training should include various failure modes of the VLA and could be expanded to include judgment training for winds, ship motion, aircraft failures, and diversion criteria. The provision for this type of training prior to deployment would greatly increase the experience and capabilities of the pilots at sea. Safety would be expected to improve as a function of the added experience. High training transfer is a must in this critical area. Caution must be exercised not to permit any form of negative training that might lead to undesirable procedures or habits.

Of course, the principal usage of the trainer is for initial training in the specific type of aircraft. In this situation, the trainer receives a less critical review but the requirement for high fidelity is no less important. The quality of training can significantly improve and the time required to achieve a desired level may be shortened.

RESEARCH AND DEVELOPMENT

Because the simulator is validated and manned (rather than a computer model), the training device becomes a valuable research and development tool. In some investigations a fleet trainer such as the SH-2F WST may be of more value than a dedicated research device because of its documented fidelity. Also, a direct comparison with existing fleet performance is provided. Evaluation of modified VLA for example may be more economically and efficiently performed on the simulator. Reduced cost, less logistical support, more controlled tests, more timely results, and better test conclusions are a few of the potential gains made possible by use of the validated flight trainer. It is not suggested that simulator usage replace actual aircraft outfit and trials - but preliminary investigations performed in the trainer should be used to reduce the scope of and more efficiently prepare for actual flight evaluation. Improved safety in T&E efforts is to be gained by prior buildup in validated flight trainers. This concept is presently in use at NAVAIR-TESTCEN wherever possible.

CONCLUSIONS

The future of the USN, as presently envisioned, holds a significant expansion of small aviation units dispersed among numerous small deck ships. Present helicopter operations, particularly in the LAMPS community, have established the groundwork from which this future will be developed. Training levels required to operate in this demanding environment are high. Safety must remain a key element in these operations if combat effectiveness of our crews and aircraft are to be maintained. Flight simulators have become widely accepted for maintaining pilot proficiency and providing tactical training. Those trainers that have been properly validated and show a high level of fidelity with their design basis aircraft have been most successful at establishing a high level of training transfer. Now high fidelity trainers equipped with sophisticated motion and visual systems are technically capable of even greater effectiveness. Helicopter/VSTOL operations from small deck ships are possible. However, the depth of simulation must include numerous environmental factors such as turbulence, ship motion, and VLA. Of particular importance is the fidelity of the visual system. It must be extremely high in areas such as dynamic response, FOV, and scene content. These continuing improvements will generate increased fidelity, higher quality training, and eventually the ultimate goal - increased effectiveness and safety in the operational environment.

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MILITARY USERS OF CALLIGRAPHIC COMPUTER GENERATED VISUAL SYSTEMS

U.S. Navy	U.S. Air Force
F-14A	A-7D
F-4J	A-10
A-6E	C-5A
EA-6B	C-141
SH-2F	F-4E
S-3A	F-16
E-2C	C-135B
P-3C	T-37
	T-38

Royal Swedish Air Force

JA-37

Royal Saudia Air Force

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